Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 14 (2012) 1355 – 1361

Energy Procedia

2011 2nd International Conference on Advances in Energy Engineering (ICAEE 2011)

Voltage travelling wave based smart re-closure for cables and overhead mixed lines

Xiang-jun Zeng, Hui Pan, Hui Liu, Xin-xin Hu, Xiao-long Luo

School of Electrical & Information Engineering, Changsha University of Science and Technology, Changsha 410076, China

Abstract

With the rapid development of cities, more and more cables and overhead mixed lines are applied into electrical power network. It is difficult to define overhead line fault and cable fault, so whether to bring the re-closure into service is an urgent problem for operators to tackle. In order to solve this problem, a novel smart re-close scheme for cables with transmission lines based on voltage travelling wave is developed**.** Reclosing scheme is determined according to the result of fault location: re-closure signal is locked when cable fault happens, otherwise, be opened. Self-developed PCB sensor is adopted to extract voltage traveling wave and then detected by hardware circuit in the paper. Compared with traditional traveling wave detection, which requires high-speed A/D acquisition, the proposed approach has the advantage of low price, easy to realize and the positioning accuracy is less than 50 meters. In addition, the module of fault location-reclosing can be integrated in the relay protection. EMTP simulation results show that, the novel scheme is an effective and practical re-closure way for cables with transmission Lines.

Keywords: Mixed lines; Smart re-closure; PCB Sensor; Voltage traveling wave; Hardware detection.

1. Introduction

It is tend to replace the overhead lines by cables to beautify circumstances and reduce impropriating ~~field with the vigorous development of urban cities c~~onstruction [1-2]. As a result, more and more combined transmission lines, which are consisted of overhead lines and cables, are widely used.

Line protection devices are configured with reclosing function generally. However, cable faults are usually permanent fault, to start re-closure will give a catastrophic effect to cables and increase injury degree and fault disturbance to power grid. In that case, many regions are forced to retire reclosing from

Xiang-jun Zeng is with School of Electrical & Information Engineering, Changsha University of Science and Technology, Hunan Province, 410076, P. R. China (e-mail: eexjzeng@csust.edu.cn)

Hui Pan is with School of Electrical & Information Engineering, Changsha University of Science and Technology, Hunan Province, 410076, P. R. China (Tel:13487591732; e-mail: 1345428502@qq.com)

doi:10.1016/j.egypro.2011.12.887

use. But most trip faults of mixed lines are caused by overhead lines and are mostly temporary fault. It will cause power failure of the whole mixed line as well as affect power supply reliability seriously without re-closure [3]. Currently, reclosing scheme, which is suitable for practical application of engineering, is desperately needed.

Scheme proposed in the first category needs to give consideration to cable type, laying mode, operating status and so on. Line structure and parameters based mixed line reclosing technology is proposed to improve power supply reliability by the greatest extent. Yet, it depends on human to judge whether to launch into reclosing according to the line situation, and needs to change with extension of line. In short, it is not come up to the requirements of smart grid.

Voltage travelling wave based cables and overhead mixed lines intelligent reclosing is proposed on the basis of travelling wave location in the paper and can be embedded in relay protection. Theoretical analysis and simulation results show that the scheme is feasible.

2. Traveling wave fault location

2.1. Traveling wave extraction

Due to the complexity of cables and overhead mixed lines structure, dispersion phenomenon of travelling wave generated in fault point is seriously when its transmits to both ends. Attenuation, superimposed and distortion occurred in the progress of transmission, which present the travelling wave extraction with difficulties.

PCB-type travelling wave sensor is a kind of Rogowski coil based transformer which conductors are evenly distributed on printed circuit board [4-5]. Digital processing technology is applied. Printed circuit board of non-iron core structure is used as skeleton. It is in good linearity, magnetic saturation and hysteresis never occur. It is able to measure signal whose rise time is in nanosecond.

We verified that by experiment: Coil wave process of voltage transformer includes electrostatic induction, electromagnetic induction and self-oscillation. Polarity of voltage travelling wave signal generated by electrostatic induction consistent with the primary signal, so the crest of travelling wave and its polarity can be transmitted precisely without delay [6]. In this paper, travelling wave signals caused by fault outlets in substation was extracted at all through self-developed PCB sensor connect to voltage transformer, which is easy to realize and in low cost.

2.2. Traveling wave detection

Currently, travelling wave based protection and control are mostly achieved by current travelling wave signals that extracted from secondary side of three-phase current transformer. Vigorous hardware and software are required to support high-speed A/D conversion and complex analysis and calculation. Otherwise, it is susceptible to anti-jamming performance of A/D sampling chip, accuracy, sampling rate, SNR and so on. Therefore, it is in high cost and its accuracy is limited. In this paper, hardware detection circuit is used to detect voltage travelling wave and accuracy is improved significantly.

Figure 2.1 is a block schematic diagram of hardware detection circuit. Small signal amplification circuit reversely enlarges millivolt-level voltage travelling wave signal which is similar with parabola and induced from secondary side of PCB Sensor, making it convenient for next detection. Amplitude detection is used to judge amplitude size. If amplitude detection outputs low level, polarity and integration detection are not required. Only does amplitude detection output high level, polarity judgment is required and then to determine the direction of travelling wave. Since travelling wave transformer is inductive load and has differential feature, integral circuit is adopted to revert travelling wave signal as auxiliary criteria of travelling detection, which can improve immunity effectively. At last, CPLD is used to record fault travelling wave data flow.

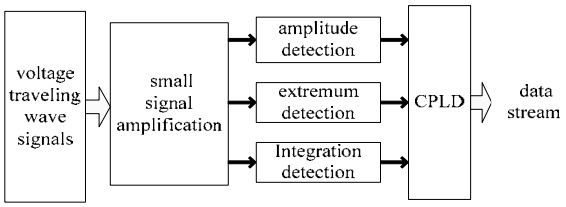

Fig 2.1 Hardware detection circuit

Hardware detection circuit is used to catch the crest of travelling wave, making it have features like simple structure, high speed and accuracy. Compared to traditional software detection (such as wavelet transform), this method can simplify hardware resources and detect arriving time of travelling wave precisely.

2.3. High accuracy synchronous clock

Infected by jamming-signal and losing satellite tracking, civil GPS-clock is difficult to satisfy the requirement of power system protection and control for its low reliability. Method for correcting the GPS-clock with high performance price ratio through information fusion was proposed by author's research group, which is not only reduce the random error of GPS-clock but also eliminate the accumulative error of crystal oscillator, is capable of recording the arrival time of travelling wave [7-9].

Precise fault point position can be gained by using double-end wave positioning equation, and location error is less than 50m.

3. Smart re-closure

3.1. Re-closing process

The wiring diagram of cables and overhead mixed lines is shown in Figure 3.1. MP_1, P_2N are first and last section overhead lines, respectively. P_1P_2 is underground cable.

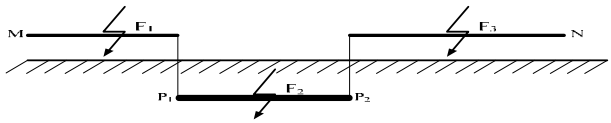

Fig 3.1 Hybrid line schematic diagram

Figure 3.2 is reclosing process diagram. PCB sensor connect electromagnetic voltage transformer to extract travelling wave signal, and detected through hardware detection circuit. Fault point position can be precisely calculated combining with high accuracy synchronous clock. If fault occurs on line P_1P_2, re-closure is quitted. If fault occurs on line MP_1 or P_2N, re-closure operated. To ensure the reliability of reclosing and the accuracy of fault location, reclosing will be quitted when fault point is on overhead line and about 50m away from node P_1 and P_2.

3.2. Realization of reclosing

Cables and overhead mixed lines usually appear in 110kv voltage and below. Three-phase one time reclosing is applied [10].

Block diagram of reclosing is shown in figure 3.3. Fault travelling wave signal is extracted by PCB Sensor. The crest of voltage travelling wave is detected through hardware detection circuit. GPS time unit is to record the arriving time of first travelling wave. Once fault happens, travelling data and time information recorded by fault record unit and GPS time unit are transformed to fault location host through optical fiber by travelling wave location device. Then fault location host completes calculation of fault position, storage of database and inquiry, determination of fault section.

Re-closure is now integrated in microcomputer relay protection and can be locked by manual, insufficient pressure, arbitrary signal and so on. The above fault location signal is connected to arbitrary signal lockout loop.

Overhead line failure will establish a low level at the output of fault location module, so the blocking signal does not function. The steps of reclosing are as follows:

1. Reclosing start according to the principle of control switch is not corresponds to the position of circuit-breaker;

2. Timing component: see to it that there is enough time for floating time and reverting time of breaker operation mechanism after breaker disconnects to ensure reclosing successfully.

3. One-time closing pulse component: to ensure the reclosing device act only once a time.

4. Actuating component: the effect signal is sent to the closing circuit and signal circuit, and then action signal is sent to circuit breaker to reclosing on.

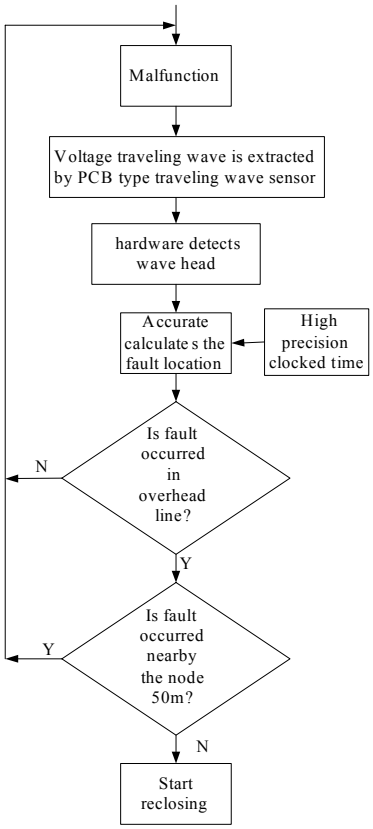

Fig 3.2 Reclosing flowchart

On the contrary, arbitrary blocking signal output high level to lock the reclosing when fault occurs in the cable. The location- reclosing module can be integrated in microcomputer relay protection, which can complete the travelling wave fault Location within 0.1S after the failure and identify the fault section for intelligent re-closing. It can produce remarkable economic and social benefits and maintain the safe operation of power grid.

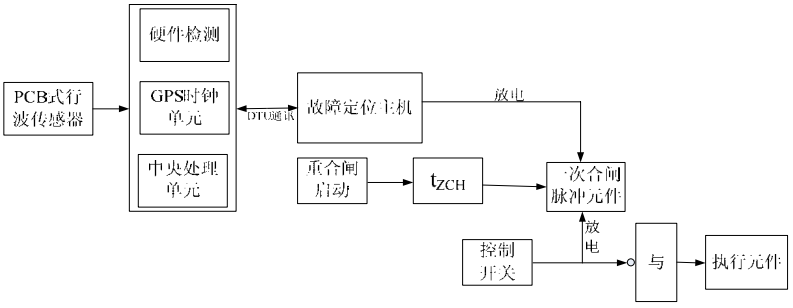

Fig 3.3 Block diagram of reclosing

4. Co-ordination with relay protection

Acceleration protection before reclosing refers to cut off the line instantly and blindly when the fault happens. Then, the second protection acts selectively when permanent fault occurs. However, re-closure will be locked supposed there is a cable failure according to the scheme, and it will result in large-scale blackout. The worst cases can lead to power failure of all users that connected to this line, when fault occurs on terminal wires.

With consideration of the above problem, acceleration protection after reclosing was adopted in this paper. Protection cut off the line in selective way and the reclosing start in case of overhead line fault, and then to speed up protection act and cut off the line if it is permanent fault. Otherwise, Protection tripping selectively and reclosing locked.

5. Simulation analysis

To illustrate the performance of the proposed smart re-lose scheme, B-type of 110kv combined transmission lines, which consists of 20km overhead line and 10km underground cable and 30km overhead line, are simulated using EMTP/ATP, the simulated results are dealt with MATLAB.

The line structure is show in fig. 4.1. The parameters of cable are: L1=0.4278mH/km, C1=0.2811uF/km, R1=0.024Ω/km, L0=1.5338mH/km, C0=0.1529uF/km, R0=0.412Ω/km. The parameters of overhead line are: L1=1. 326 mH/km, C1=8. 688 nF/km, R1=0. 3317 Ω/km, L0=4. 595mH/km, C0=4. 762nF/km, R0=0.4817 Ω/km.

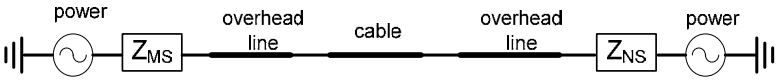

Fig 5.1 Simulation system wiring diagram

Table 1 Simulation results of single-phase earth fault

fault location (Km)	transition resistance (Ω)	locate result (Km)	status of re-closing
2	50	2	starting
	100	2	starting
	200	2.01	starting
14	50	14	starting
	100	13.98	starting
	200	14.03	starting
26	50	26	locking
	100	26.01	locking
	200	26.02	locking
30	50	30	locking
	100	30.03	locking
	200	29.96	locking
30.04	50	30.04	locking
	100	30.02	locking
	200	30	locking
47	50	47	starting
	100	47	starting
	200	46.98	starting

Table 2 Simulation results of two-phase fault

fault location (Km)	Transitional type	locate result (Km)	status of reclosing
2	two-phase fault and transition resistance is 50Ω	1.98	starting
14		14.00	starting
26		26.03	locking
30		30.03	locking
30.04		30.02	locking
47		46.97	starting
2	two phase short circuit	2.03	starting
14		14.01	starting
26		26.03	locking
30		29.98	locking
30.04		30.03	locking
47		47.00	starting

Table 3 Simulation results of three-phase fault

fault location (Km)	locate result (Km)	status of reclosing
2	2.04	starting
14	14.00	starting
26	25.98	locking
30	30.01	locking
30.04	30.06	starting
47	46.99	starting

Simulation results obtained from different faults types happened in different place are shown in Tables 1-3. It can be seen that the presented scheme gives precise fault location, and mean error be controlled in a mini confine, thus, reclosing act accurately and hardly influenced by fault resistance and faults types.

6. Conclusion

A novel smart re-close scheme for cables and overhead mixed lines based on voltage travelling wave is presented in this paper. Its specific merits are as follows:

1. It use the self-made PCB-type travelling-wave sensor for voltage travelling waves, having high accuracy, easy erecting;
2. Compared with the traditional software detection (i.e. wavelet transform requires High-speed A/D acquisition and complex calculations and analysis), adopting hardware detection circuit to detect the crest of travelling wave has the advantage of high measuring precision, low price and easy to realize;
3. It is able to locate the fault location accuracy for the positioning accuracy is less than 50 meters;
4. The module of fault location-reclosing can be integrated in the relay protection and is an effective re-close scheme for cables with transmission Line according to the simulation results.

References

[1] Nan Jiang, Yu-lin Xie, Jun-ping Hou. Reclosing Mode Of Cable-overhead Mixed Lines[J]. *Automation of Electric Power Systems,* 2010, 34(3):112-115..

[2] Zhen-tao Xin, Lei Wang, Hong-yan Jiang. Smart Re-close Scheme Of Combined Overhead Line with Underground Power Cable. *2010 International Conference on Power System Technology, Hang Zhou,* 2010..

[3] Zhen Huang, Ping Chen. A Fault Location Method For High-voltage Overhead Lines Combined With Underground Power Cables Based On Double-ended Travelling Wave Principle[J]. *Sichuan Electric Power Technology,* 2008, 31 (sup): 1-4.

[4] Xiang-hui Chu, Xiang-jun Zeng, Hong-jiang Ma. Rogowski Sensor for Power Grid Travelling Wave Based Fault Location. *The 9th International Conference on Developments in Power System Protection. Glasgow,* 2008.

[5] Chao Zhuo. Research on Power Gird Fault Travelling Wave Detection Device Based on Substation Secondary Signal[D]. *Changsha University of Science and Technology ,* 2010..

[6] Xiang-jun Zeng, Zheng-yi Liu, Ming-zhi Qu. Simulative Analysis and Experimental Test of the Transmission Characteristics of Transient Travelling-wave in Transformer[J]. *Journal of Changsha University of Science and Technology(Natural Science),* 2004, l1(1):71-75..

[7] Xiang-jun Zeng, Xiang-gen Yin, K K Li. Methods for Monitoring and Correcting GPS-clock[J]. *Proceedings of the CSEE,* 2002, 22(12):41-46.

[8] Xiang-jun Zeng, Xiang-gen Yin, Lin Gan. Clock of High Accuracy Implemented by Crystal Oscillator in Synchronism with GPS-clock[J]. *Automation of Electric Power Systems,* 2003, 27(8):49-53.

[9] Lewandowski W, Petit G., Thomas C. Precision and Accuracy of GPS Time Transfer [J]. *IEEE Transactions on Instrumentation and Measurement,* 1993, 42(2):474-479.

[10] Yu-ze Yu, Jian Tan, Gong-xin Li. A Survey on Fault Location Methods for Hybrid Transmission Lines Consisting of Power Cables and Overhead Lines. *Power System Technology,* 3017):64-69.